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Energy Systems Group. Annual Progress Report 1 January - 31 December 1981

Mackenzie, Gordon A.; Larsen, Hans Hvidtfeldt

Publication date:
1982

Document Version
Publisher's PDF, also known as Version of record

Sales distributors:
Jul. Gjellerup, Sølvgade 87,
DK-1307 Copenhagen K, Denmark

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ISBN 87-550-0852-
ISSN 0106-2840

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Risø-R-464

Energy Systems Group Annual Progress Report 1 January - 31 December 1981

Edited by
Gordon A. Mackenzie and Hans Larsen

Risø National Laboratory, DK-4000 Roskilde Denmark
May 1982

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ENERGY SYSTEMS GROUP

Annual Progress Report 1 January - 31 December 1981

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Abstract. The activities of the Energy Systems Group at Risø during 1981 are described. The work comprised participation in the Danish Energy Plan EP-81, development and use of energy-economy models and analysis of technical and economic aspects of specific parts of the Danish energy system. Recently started projects are described briefly. A list of staff indicating experience and areas of interest is included.

EDB descriptors: DENMARK; ENERGY ANALYSIS; ENERGY DEMAND; ENERGY MODELS; HEATING; PLANNING.

UDC 620.92(489):65.012.122

May 1982

Risø National Laboratory, DK 4000 Roskilde, Denmark.

ISBN 87-550-0852-6
ISSN 0106-2840

Risø Repro 1982

CONTENTS

1. INTRODUCTION

The Energy Systems Group (ESG) at Risø National Laboratory is multidisciplinary and directly responsible to the Risø board of managers. The Group was first established in 1977, at that time as a temporary group. The overall aim of ESG is to perform technical and economical assessments of the Danish energy system and its interrelationships to the international energy system. This work involves detailed analyses of selected parts of the energy system as well as technical and economical investigations of specific energy technologies. At present, the staff consists of 4 economists and 6 scientists together with 4 research students, 1 part-time consulant, 1 part-time undergraduate assistant, and 2 secretaries.

The work of ESG extends over a wide area. From an application point of view, the Group's activities can be divided into three main categories:

a. Danish energy planning
b. Research and development
c. Contract work

In the following a short summary is given of the major tasks undertaken within each category.The activities within Danish energy planning in 1981 are described in detail in Chapter 2 of this report. Most of the work here is carried out for the Energy Ministry. By far the largest single task undertaken by ESG in 1981 was participation in the work concerning the new Danish Energy Plan (EP-81) which covers the period from the present to the year 2000. The possible developments in energy demand were investigated as well as the economic consequences of the various alternative possibilities for supplying this demand. In addition, a special investigation was carried out, although in less detail, on the longer term situation, from 2000 to 2030. The Energy Plan was published in November 1981.

Research and development is described in Chapters 3 and 4 of this report. This topic includes energy model development for the

European Commission, own model development, and finally four postgraduate research projects. The EC-model work includes the collection of data for Denmark, performance of case studies, and to some extent development of computer models. The work is carried out in close collaboration with the other member nations of the EEC. The model-complex is able to handle both national and multinational calculations for the EEC as a whole. ESG's own model development has primarily been centered around further development of the DES-model.

The postgraduate research projects have dealt with:

- Simulation of combined heat and power production
- Pricing policies and tariff structures
- Economic assessment of energy technologies
- Economic models and energy planning.

Of the work carried out under contract in 1981, an evaluation of publicly available Danish energy statistics can be mentioned. Another contractual task consisted of participation in an evaluation of the security of supply in the natural gas network currently being built in Denmark. At the end of the year a study aimed at evaluating the technical and economical merits of small coal- fired heating plants was initiated.

The work for the Energy Ministry on the new energy plan played a dominant role in the activities of the ESG. However, it has been possible to start two new R & D projects: "Economic assessment of energy technologies" and "Energy Planning and economic growth models". It should be mentioned that during 1981 a reassessment of the various activities at Risø was undertaken. As a result of this it was found that in the future ESG should aim at a reasonable balance between the three main areas of work mentioned above. This means that it is intended to increase the amount of contract work in future programmes. In Chapter 6 we present a brief description of new projects on which work will start during 1982.

The work of ESG involves collaboration with other organisations such as the electrical utilities, The Danish Ministry of Energy

and the Danish Energy Agency. In addition, members of the Group take part in various national and international committees such as a joint Nordic group for non-nuclear energy research, the European Commission Advisory Committee on Programme Management (ACPM) with responsibility for energy modelling, and the Danish National Committee for the World Energy Conference.

The group has participated in the IEA project concerning energy technology characterization. Furthermore, a close collaboration has been established with the Science Policy Research Unit (SPRU) at the University of Sussex, U.K. One staff member from ESG spent two months at SPRU during 1981. Likewise, a staff member from SPRU visited ESG as a summer guest for 6 weeks.

2. DANISH ENERGY PLANNING

During 1981 the Energy Systems Group's main effort in the field of national energy planning was directed towards the Danish Energy Plan 81 and related studies, all under the auspices of the Ministry of Energy. In March 1981 the Ministry of Energy initiated a study of the long term prospects for energy planning, going beyond the 20-year time horizon of the quantitative forecasts of EP-81, as noted earlier. ESG was also involved in this latter study. Apart from the above-mentioned tasks ESG participated in various other activities in relation to the Ministry of Energy.

2.1. Energy Plan 81

The work on the new Danish Energy Plan was originally started in the spring of 1980 and the final report, entitled Energy Plan 81, was published in November 1981. The organisation of the study is described briefly below.

A number of working groups were set up to study the demand, supply, and administrative aspects of the Danish Energy System. The topics studied by these groups were:

1. Process energy
2. Space heating
3. Transport energy
4. Electricity demand
5. Imported energy
6. Danish oil and gas production
7. Technical aspects of the supply system
8. Economic analysis of the electricity generating system
9. Means of regulating demand

The Energy Systems Group was represented in Groups 1 to 8.

The Energy Plan as published consists of an assessment part, and a part outlining the Government's energy policy. The overall aim of the assessment part is to give a detailed description of the possible developments in energy demand between now and 2000, and the alternative possibilities of supplying this demand. The energy demand forecasts were carried out for three different situations: expected moderate economic growth with either unchanged or increased demand regulation, and low economic growth with existing regulation.

On the supply side, the energy plan investigated a number of alternative development plans with and without nuclear power, with more or less utilisation of renewable energy sources and decentralised combined heat and power stations.

In order to establish the best possible foundation for the formulation of a national energy plan the various possibilities, or scenarios, were analysed with respect to the more important consequences for society, i.e. investments, running and fuel costs, effect on the employment situation, foreign exchange, and environmental effects.

A short description of the ESG contributions to the various working groups is given below.

2.2.1. Process energy

The study was carried out at a 10-branch level and 3 energy forms were considered: solid fuels, liquid fuels, and electricity. The historical analysis was based on the energy/output ratios for individual energy forms and branches. Because of the lack of suitable data over a longer time period this analysis was limited to the period 1970-78. Observed changes in these ratios were related to changes in technology, investments, employment and fuel prices and the future trends were estimated on the basis of such historically determined relations together with projections of the underlying factors (technology, fuel prices, etc.).

The main contributions of ESG in this group consisted of the construction of (i) a consistent data set to be used for the historical analysis and (ii) the analysis and forecasts for the agriculture, horticulture, fisheries, and building and construction sectors.

2.1.2. Space heating

For each of the three situations mentioned above a forecast of the useful energy demand for space heating and domestic hot water was made. These forecasts were calculated from building areas and unit energy demand per m^2 in existing and new buildings of various kinds and uses.

The ESG contribution to this working group was the construction of a new module to be incorporated in the DES-model for this calculation (see Section 3.1.).

2.1.3. Transport energy

The object of the transport energy working group was to project the transport demand (in passenger-km and ton-km) for each mode of transport and hence to calculate the energy demand based on the expected development of the fuel economy of vehicles. Most of the work within this group was carried out by the Danish Ministry of Public Works also called the (Traffic Ministry). ESG played a relatively minor role in the group.

2.1.4. Electricity demand

A simulation model, based on the appliance-stock approach, was constructed for the household sector. Using this model the consumption of electricity was related to the stock of household appliances and their use. Forecasts of annual purchases and the rate of depreciation were used to compute the stock of major energy consuming devices, such as refrigerators, freezers, etc., taking into account the possibility of reaching a saturation level for these appliances. The stock of minor energy-consuming devices (televisions, vacuum cleaners, etc.) was obtained using saturation curves. The total electricity demand for appliances was then calculated using exogenous figures for the specific energy consumption and the frequency of use of these devices. The electricity demand for lighting was estimated separately and added to the total for appliances.

The projections for industry were based on a sectoral approach in which industry was divided into a number of sectors for which electricity demand was computed separately. A similar method was also used for the service sector.

Although ESG participated in the forecasting for all three areas, the group's main contribution was in the construction of the appliance-stock model. Most of the work on the industrial electricity consumption was carried out by the working group for process energy. The forecasts for the service sector were done by ESG exclusively, but, in contrast to the forecasts for households, the methods used were relatively simple.

2.1.5. Imported energy

The purpose of this working group was to study the supply situation for imported fuels and to forecast the possible developments in fuel prices. The latter task was delegated to a subgroup in which ESG played a leading role.

The subgroup established three alternative price profiles for crude oil assuming increases of 50%, 100% and 200% by the year 2000. In the two high profiles it was assumed that most of the growth occurred in the middle part of the period with a flat-

tening towards 2000. The low profile was assumed to exhibit exponential growth throughout the period with an annual increase of 2%.

A simple model was established for determining product prices on the basis of crude prices. The price of natural gas was expected to develop as a fixed fraction of the oil price. The same applies to the import price of coal in real terms. It was assumed that nuclear fuel prices develop in proportion to those of crude oil.

2.1.6. Domestic energy production

The working group produced a comprehensive description of the situation with respect to Danish energy resources, published as an annex to the energy plan. The description focused on the offshore activities in the North Sea and gave a thorough presentation of the historic background, the present estimate of the available resources, possible production profiles, etc. ESG did not directly contribute to the effort but merely followed the work of the group.

2.1.7. Technical aspects of the supply system

The general aim of this group was to formulate and evaluate plans for the energy supply system which would satisfy the demand projected by the demand groups. This work involved the consideration of development plans for the electricity generation and distribution systems, district heating, natural gas, the introduction of renewable energy sources, etc.

ESG undertook the collection and evaluation of technical and economic parameters for energy conversion systems ranging from domestic heating appliances to power stations.

In order to evaluate these plans, a number of alternative supply scenarios were defined. These were combined with the three demand projections and the DES-model was used to calculate the consequences in terms of final energy demand and the expenditure for fuel, investment, and operation and maintenance. These calculations were undertaken by ESG.

2.1.8. Economic analysis of the electricity generating system

This working group was first established in May 1981 to update and revise earlier studies on the generating cost in a future electricity system with or without nuclear power stations.

The study was divided into two parts: comparisons of (1) single power stations and (2) alternative developments of the electricity generating system.

Three types of power-stations were compared, namely, a 600-MW coal-fired unit, a 900-MW light-water nuclear reactor, and a 635-MW CANDU heavy-water reactor. It was assumed that none of the units would supply CHP for district heating. Investment fuel, operation, and maintenance costs per kWh were calculated under different assumptions with regard to prices, interest rates, etc.

Two alternative developments of the Danish electricity generating system were studied over a period of 40 years from 1981.In both cases CHP-generating units are built to fulfil the requirements of the heat plan. Further development of the generation system is based on either 600-MW coal-fired units or 900-MW nuclear units. The DES-model was used for the study.

2.2. Long-term Prospects of Energy Planning

In March 1981, the Ministry of Energy formed a working group with the aim of investigating the long-term prospects of energy planning, i.e. the time period up to the year 2030. One member of ESG participates in this group. The preliminary findings of this group were published as an appendix to the Energy Plan.

The scope of work of this long-term energy planning group is to analyse, in relatively general terms, the long-term interrelationship between the energy demand in Denmark and the national economy, taking into account the development in energy prices, production structure, and demand patterns.

The justification for undertaking a study of the situation in such a distant future is that the Danish energy system predominantly consists of installations with a construction time of up to ten years and an expected useful lifetime of at least 25-30 years. Examples of such installations are power plants and the district heating and natural gas networks. The main emphasis of this investigation is to identify and characterize the interrelationships in the development after 2000 which may have an important impact on the decisions to be made before then. With a time horizon so far in the future it is necessary to investigate the demographic development, changes in life style, etc., in addition to the more traditional economic and technical considerations. The main contribution to the work from the Energy Systems Group has been to formulate the expectations as to technological development of importance for the energy sector and to consider the interplay among the various parts of the Danish energy system.

3. INTERNAL PROJECTS

3.1. The Danish Energy System Model - DES

As mentioned in the 1980 Progress Report the DES-model has been developed to simulate the total Danish Energy System and to calculate the consequences of various projections of energy consumption and the energy supply system. During 1981 the DES-model was used to describe the various scenarios that were specified in EP-81. At the same time, ESG has developed a new model structure in order to provide the policymaker with a flexible and easily understandable tool for translating energy demand forecasts into primary energy requirements and their economic consequences.

The DES model is based on one which was developed by the electrical utility ELKRAFT and named Long-term Planning System (LPS). The purpose of the latter model was the simulation of the operation of a system of power stations that includes CHP, together with a calculation of the investment and running costs.

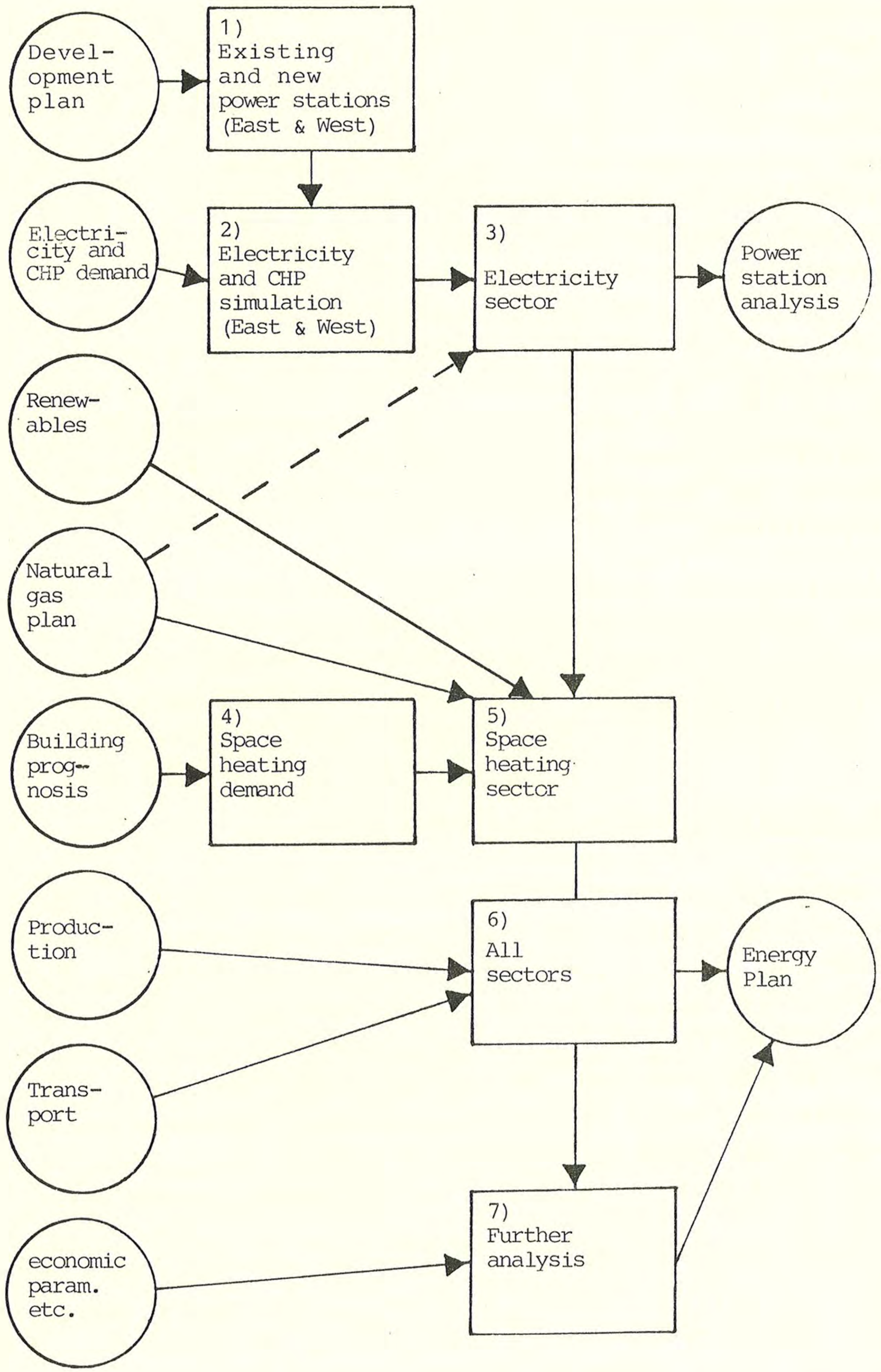


Figure 3.1. Main structure of the DES-model.

This model was redesigned and extended by ESG for use in a study of electrical heating by adding a section which calculated the economic consequences of the energy demand in the space-heating sector.

The DES-program by which a model can be constructed contains the following elements:

- 1000 accounts for a maximum of 40 years
- simple arithmetic rules of calculation for accounts
- a number of functions, i.e. relations between accounts for one or more years
- routines for input data
- routines for output tables and curves.

One of the functions mentioned above is the simulation model for electricity and CHP. The input data of this function are:

- parameters of size, heat rates, availability, etc. for each power-station
- load duration curves for electricity demand winter and summer
- demand for electricity specified by maximum load and load factor
- CHP-demand winter and summer in cities and regions with district-heating grids connected to power-stations
- fuelprices and unit operating costs.

The results of the simulation are the production of each power-station and the associated running costs.

Figure 3.1 shows a simplified description of the structure of the DES-model which was used for the EP-81 study. The blocks denote model-phases consisting of basic parameters, rules of calculation and functions, and the circles denote exogenous input data or output tables, etc. by which various scenarios can be described.

In Phase 1 a description of the stock of power-stations for each year in the planning period is established. Old ones are taken out and new units are put into operation according to a development plan. Investment costs of new units are calculated.

In Phase 2 production by windmills and biogas installations are subtracted from the total electricity demand and the required electricity production from thermal stations is found. Then the simulation model is run.

These Phases are used for each power generating system (east and west of the Great Belt). The results are aggregated in phase 3, and primary energy requirements are calculated together with annual costs. This part of the model was used as a separate model for the economic analysis of the electricity generating system (see Section 2.1.8).

Phase 4 is a module in which the space-heating demand is calculated as the product of a prognosis of future buildings area and unit demand in buildings of various age and kind.

The distribution of heating forms and primary energy requirements for space heating are calculated in Phase 5. The supply of district heating from CHP, natural gas and waste incineration, etc. is known from the electricity sector of the model or is provided exogenously, and the rest of the supply for district heating is covered by fuel oil. For single-family houses the numbers of installations for district heating, electrical heating, natural gas, and renewables (wind, biogas, straw, heat-pumps, etc.) are known, and the rest of the houses are heated by oil burners supplied by gas-oil. Other buildings not connected to the district-heating grid are supplied either by fuel oil or by gas-oil.

The fuel demands in the production and transport section are added in Phase 6, and the primary energy requirement for all sectors by fuel types is found together with annual costs for investment, fuel, and operation and maintenance.

Phase 7 is a separate module for further analysis, e.g. present values of expenditure, or employment and foreign trade consequences.

3.2. Energy planning and economic growth models

This Ph.D. project was initiated in 1981 and is being carried out in cooperation with the Institute of Economics, University of Arhus. Its purpose is to develop a long-term (i.e. about 20 years) economic model for Denmark, which adequately incorporates the energy sector and could be used for energy planning purposes.

During 1981 the main emphasis has been placed on theoretical studies and a survey of energy economy modelling in other countries. The outcome of these studies can be summarized in the following 4 essential features which a long term planning model for Denmark should exhibit:

(1) It should focus on energy-economy interactions, i.e. be able to describe the interactions between energy prices,- energy consumption, and the growth and structural development in various sectors of the economy.

(2) The specification of the most energy intensive demand sectors and the energy supply system should be based on an interplay between economic and technological factors. In the long run one must consider the utilization of new technologies and the technical as well as economic substitution possibilities between energy and other factors of production, between various fuels and between various energy demand and supply technologies.

(3) It should incorporate the main energy policy instruments, including demand regulation measures (e.g. pricing policies, taxes, various conservation measures, etc.) as well as supply measures (e.g. investments in supply technologies, R&D, etc.).

(4) It should be dynamic in structure, enabling the analysis of dynamic adjustment towards desired paths of target variables for alternative combinations of policy variables.

While each of these features is generally accepted as being of vital importance, very few models, if any, exhibit all of them. In particular, research into the aspects covered in (2) is still in its infancy. As a general framework of the project we intend to use the Norwegian MSG-E (Multisectoral Growth-Energy) model, a simplified version of which has been implemented for Denmark by the Economic Council. We intend to extend this model gradually, giving highest priority to the technical-economic interplay.

3.3. A model for simulation of combined heat and power production

The vast increase in combined heat and power production, which is taking place at present, is introducing new problems in the planning of power plant development and in the daily running of the CHP generation system.

A Ph.D. project dealing with these problems is being carried out by ESG in collaboration with the Electric Power Engineering Department of the Technical University of Denmark. The main aim of the project is to develop a computer model to simulate the operation of the electricity production system (including CHP plants). The model can be run for either of the two electricity supply areas corresponding to those served by the two utility cooperatives ELSAM (Jylland, Fyn) and ELKRAFT (Sjælland, Lolland, Falster, Møn). It is possible to simulate the detailed operation of the system over a short period of time, taking into account the problems brought about by co-generation, in order to find an optimal strategy for unit commitment and load dispatching. Moreover, it is possible to run more simplified simulations for a period of years in order to make an economic evaluation of hypothetical development plans. The value of different components of the system such as windmills or heat storage facilities can be investigated by performing simulations with and without these components.

During 1981 an optimisation module for heat production was developed, and in connection with this a general optimisation program was incorporated to deal with the hour-by-hour operation of heat storage.

These routines for simulation of the heat production and storage system have been combined with previously developed routines for

the simulation of the power plants including optimal unit commitment and load dispatching. The unit commitment problem is solved by an integer programming technique known as "Branch and Bound".

A preliminary version of the model was completed by the end of 1981, and it is expected that the project as a whole will be completed by the end of 1982.

3.4. Pricing policies and tariff structures for space heating

In October 1979, work was begun on a Ph.D. project on pricing policies and tariff structures for space heating. The aim of the study is to investigate the technical, economic, and political factors involved in the implementation of the Danish Heat Plan, with particular emphasis on the prices charged for the various heating forms such as natural gas, district heating, etc.

Originally it was intended to develop models which could be used to investigate the influence of the various factors on the pricing and investment decisions of the public utilities. During 1981 the work on the project consisted of:

a) the formulation of a technical/economic description of the energy systems for space heating, and

b) a study of the performance and regulation of the nationalised energy utilities in the U.K.

The latter study was carried out during a 3-month visit the Science Policy Research Unit, University of Sussex.

From the above studies, it was concluded that the most important constraints in the system under investigation are the political and legal ones involved in the Heat Plan and in other Danish planning laws. For this reason, the work on the project during the second half of 1981 was concentrated on a survey of the Danish planning laws and a study of the way in which the Heat Supply Law is administered by public authorities.

The project as a whole is expected to be completed by the end of 1982.

3.5. Economic assessment of energy technologies

In August 1981, a project aimed at elucidating the economics of various energy technologies was initiated. The technologies which will be considered are primarily in the field of renewable energy, such as heat pumps, small windmills, solar heating systems, straw furnaces, and biogas systems. Conventional energy conversion systems such as oil and gas burners and those employing electrical heating will also be studied in order to provide a basis for comparison.

The overall aim of the project is to build up a collection of computer programs for calculating economic quantities such as the effective energy price including investment cost, present value, and internal rate of return on the investment. These quantities would be evaluated with respect to both the economy of the private investor and the national economy. In addition, the impact of the various technologies on the national balance of payments and employment will be studied.

The computations will make use of statistical data on performance, lifetime, costs, etc. for each technology, and will involve a sensitivity and uncertainty analysis. The results of these computations will be presented graphically in a compatible format for all technologies investigated. It is hoped that the form of the presentation will give the appropriate decision makers a clearer picture of the economic consequences of the development of particular energy technologies.

As a first example we are studying heat pumps for space heating in single family dwellings. The duration of the project is expected to be 2 years.

3.6. Databases and other supporting software activities

A great deal of the work which is performed by ESG involves the processing of large amounts of statistical data pertaining to the energy consumption, economic activity, etc. of the various sectors of society. An important condition for such work is to have easy access to a detailed and well-documented set of data and to have the necessary computer software for data retrieval and processing. The establishment and maintenance of such databases together with the development of software can be regarded as an activity which supports the other tasks that are performed by the group.

In connection with the second part of the Macrosectoral Model project, the group acquired a statistical standard package called TSP (Time Series Processor) and implemented it on the Burroughs B6700 computer at Risø. TSP is a computer software system primarily designed for econometric analyses of time series but most of its facilities are fairly general and can therefore also provide a very useful tool for other types of analysis. The TSP program package was developed by Bronwyn H. Hall and Robert E. Hall, Stanford University U.S.A., and consists of various data manipulating facilities, estimation methods, and routines for solving simultaneous structures as well as a subsystem for performing pure matrix operations.

During the past year ESG has undertaken a total revision of the following databases:

(1) The Danish Statistical Office (DS) National Accounts Department's Input-Output Tables for 1966-76 classified into 117 sectors, 66 consumption categories, and 9 final use categories.

(2) DS's Energy Balances classified according to 117 sectors and 23 energy types for 1966-78.

The latter is complemented by the addition of statistics from the Danish Energy Agency (ENS) and the Danish Association of Electricity Supply Undertakings (DEFU) for energy and electricity for the period 1966-80.

There are, however, inconsistencies between the energy statistics of DS and ENS/DEFU because the former set is consumer oriented while the latter is supplier oriented. An investigation of these problems was initiated during 1981 and is described in Section 5.1.

Software has been developed and updated to access the above-mentioned databases and perform aggregations over specified sectors and/or energy types.

4. EUROPEAN COMMISSION ENERGY-ECONOMY MODELS

The Energy Systems Group is at present involved in the implementation and use of four separate models for the European Commission's energy modelling programme. These are the medium-term energy demand model complex, the long-term energy demand model, the energy flow optimisation model and the macrosectoral energy demand model. The last of these is at present under development while the others are fully operational.

The philosophy behind the European Commission's programme on energy systems and modelling, and details of the individual models, apart from the macrosectoral one, are fully described in the publication "Energy Models for the European Community"(1).

4.1. The medium-term demand model

The medium-term demand model consists of the 3 submodels EURECA, (macroeconomic) EXPLOR (input-output), and EDM (energy demand).

(1) Energy Models for the European Community. ed.A.Strub. Energy Policy, IPC Science and Technology Press Ltd. 1979.

EURECA is centred around a Cobb-Douglas production function, which takes into account three factors of production: capital, labour, and energy. The model computes gross national product and its single components such as private consumption, investments, etc.

The sector model EXPLOR is based on a input-output description of the intersectoral dependencies within industry. The single components of GNP are given as input (from EURECA) to this model, and its main task is to compute both the activity in each of the 15 production sectors and the corresponding cost-determined sector prices. The final results are obtained by an iterative procedure where the calculated sectorprices become input to EURECA which then recomputes the macroeconomic quantities and so on.

The production of all non-energy producing sectors, private consumption and energy prices, as computed in EXPLOR, are exogenous to the energy demand model EDM. This model calculates the total energy consumption in each of the non-energy producing sectors and in the private households. In addition, the substitution between different fuel types is determined for each sector and for households.

During 1981 the national part of the medium-term demand complex was totally restructured and updated. The sector model EXPLOR was aggregated to 15 production sectors, where previously 35 were used. Of these 15 sectors, 5 are energy producing. The new aggregation scheme is based on the Danish input-output tables and is chosen according to the importance of the sectors in the Danish energy system and with due regard to compatibility with the latest statistics.

The EDM-model was totally re-estimated using an aggregation level of 12 sectors, directly connected to EXPLOR.

A preliminary case study was worked out using this new model system. For the period 1980-1990 the main assumptions used in this case study are:

1) a 3% p.a. growth in GNP in real terms, and
2) a 3% p.a. increase in energy prices in real terms.

Table 4.1 gives the resulting development in energy consumption.

Table 4.1. Final energy demand growth rates, % p.a.

Energy type	1980-85	1985-90
Solid fuels	3.4	4.1
Liquid fuels *	1.0	2.0
Electricity	1.8	1.7
Total	1.2	2.1

* including district heating and natural gas.

4.2. The long-term energy demand model

Work has continued on the European long-term energy demand model. The model is entitled MEDEE 3 and was developed by the Institut Economique et Juridique de l'Energie (IEJE), Grenoble, France. MEDEE 3 simulates the evolution of energy demand over a period of 20 to 30 years. Energy demand is calculated for a set of consumption sectors which are, as far as possible, homogenous with respect to social need or economic activity, consumer behaviour, and technological context. The model is therefore highly disaggregated and requires a very large amount of social, economic, and technical data.

MEDEE is not an economic model like the medium-term or macrosectoral ones. It is rather a model which can be used to translate particular scenarios for the development of the socio-economic system into energy demand terms.

The work on the MEDEE model during 1981 was primarily concentrated on the running of a first simulation using the data set which had been assembled in 1980. This involved a number of runs of the

model after each of which the results were examined and the data adjusted where necessary until a consistent set of results was obtained. Because of the nature of the model such an iterative process is essential, at least in the early stages of the work, in order to check the consistency of the data, many of which are estimates based on different sources.

The aim of the present programme of work with the MEDEE 3 model is to obtain results based on similar assumptions to the medium term case studies: base case and high case. This would allow a comparison of the two models, to be made, at least for the period 1980 to 1990. Such a comparison is still planned; however, by the end of 1981 only the results for the high case were available.

The scenario data for the MEDEE 3 model can be divided into two categories:

a) Time series macroeconomic data from 1975 to 2000 for such quantities as gross national product, value added in industrial sectors, etc.

b) A set of values for the qualitative scenario descriptors which characterise the scenario through the pre-programmed tabular functions. The latter consists of tables of values, mainly growth rates, which describe quantitatively the development of particular aspects of the socio-economic system.

The results available at the end of 1981 correspond to a scenario called "high case 2" in which the price of crude oil is assumed to increase by 50% between 1980 and 2000.

We have used the appropriate projections of the recently published Danish Energy Plan EP-81 as a basis for comparison with the MEDEE 3 results. Although there are some differences in several of the assumptions of EP-81 from those used in the MEDEE 3 scenario, it is our opinion that the rough trends in energy demand should be similar in both studies. In Table 4.2. the energy demand of households as calculated by MEDEE and in EP-81 is shown. The major area of disagreement is the electricity demand. In the MEDEE model a linear increase of 50 kW/year per household was assumed in the scenario. In EP-81, on the other hand, a detailed study of household electricity demand involving a consideration of the stock and efficiencies of appliances was carried out. The latter study pointed to a considerably lower growth in household electricity consumption than had been assumed in the MEDEE scenario. A more detailed treatment of this topic is planned for a future version of MEDEE 3.

In general, the agreement between the MEDEE 3 results and those of EP-81 was satisfactory in spite of the methodological differences between the two approaches. The close aggreement between the results of the two studies confirms the consistency of the input data and the structure of the model. Future work on the model will involve the investigation of the sensitivity of the results to changing energy price and macroeconomic projections. When the consistency of the model is confirmed under these conditions it will then be possible to use it to explore the effect of different policy options.

Table 4.2. Useful energy demand for space heating and hot water and final demand for specific electricity (including cooking) in households (PJ).

	MEDEE 3 (high case 2)			EP-81 (basis)		
	1980	1990	2000	1980	1990	2000
Space heating	104	111	115	-	-	-
hot water	19	19	20	-	-	-
Space heating + hot water	123	130	135	120	130	134
Specific el.	21	27	33	-	-	-
cooking*	6	6	7	-	-	-
Specific el. + cooking	27	33	40	25	27	31

* treated as 100% electric cookers

4.3. Macrosectoral model

In 1981, ESG began working on a new model which is being developed by the European Commission. It is called the Macrosectoral Model and is a multinational macroeconomic model that focuses on energy-economy interactions and has a forecast horizon of 5-7 years. The development is coordinated by Mr. G. D'Alcantara for the Commission of the European Communities and is a continuation of the energy demand modelling program. When fully implemented it is expected that the model will replace the COMET and some parts of the existing EEC energy demand models.

Briefly, the general features of the Macrosectoral Model can be described as follows: For each of the EEC-countries a similarly structured national model is built at two different levels:

- level 1 with 9 production branches
- level 2 with about 25 production branches.

At level 1 the national models are interlinked to a multinational model via a system of bilateral trade flows. At this level the model is enlarged with relations for the trade with the rest of the world. The level 2 branches are a disaggregation of the nine level 1 branches. At this level the national models are not interlinked.

For each of the branches the model determines total output, value added, deliveries to private and public consumption, variations of stocks, imports and exports. Production is described by a production function in capital, labour, energy, and other intermediate inputs. Total private consumption is determined by a macroeconomic consumption function, and this total is allocated between 15 categories of consumer goods via a consumer demand system. Energy is integrated into the model as one of the production branches, as a factor of production and as three categories of consumer goods. Total energy consumption per branch is determined from the production function and this total is split into consumption of up to 8 different fuel types in a special energy substitution model.

During 1981 the work with the Macrosectoral Model consisted of the following stages:

(i) familiarisation with the model,
(ii) data collection, and
(iii) preliminary estimation of the energy substitution model.

The data collection was not completed by the end of 1981. This task will be continued during 1982. The main task to be undertaken during 1982 is the estimation of the model, i.e. the determination of the various parameter values. The model is expected to be fully implemented by the end of 1983.

4.4. The energy flow optimisation model

The supply part of the European Commission's energy model complex consists of the energy flow optimisation model EFOM. This model uses the technique of linear programming to find the optimal energy supply structure which satisfies the demand computed by either the medium- or long-term energy demand models.

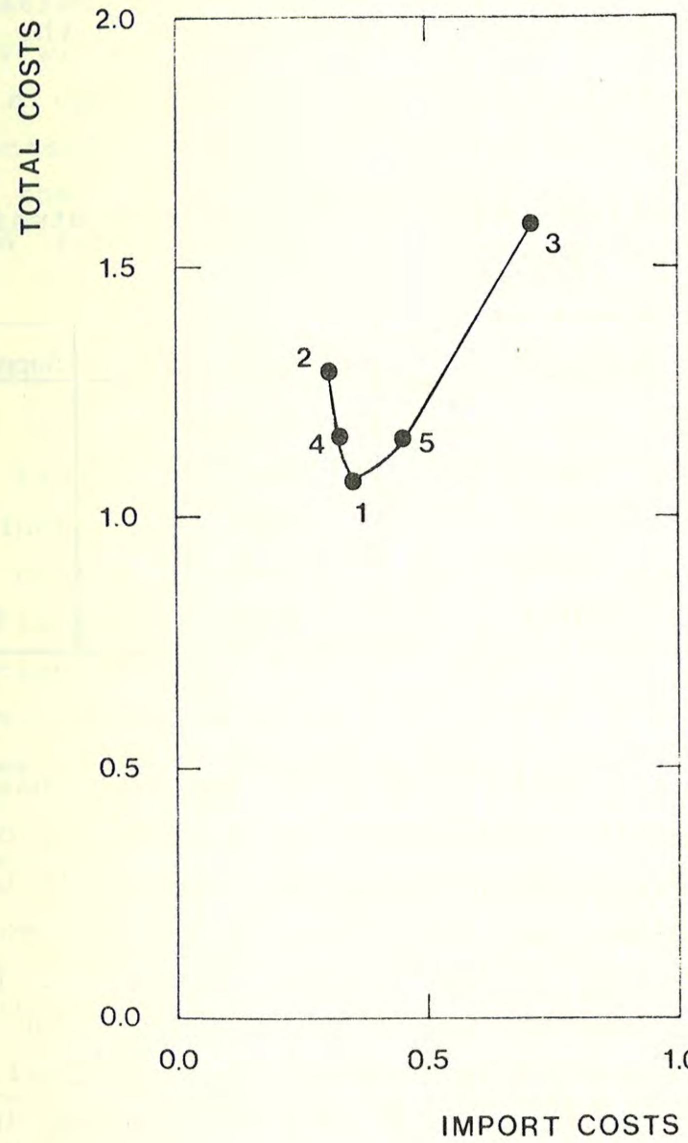
During 1981 the model was used for a study called "Escalating Supply Rationing". Five cases were run using the European Commission's computer.

The first case called the "Reference Case" is a minimization of the total actualised cost of the system. This corresponds to point 1 in Fig. 4.1.

The "Mining Case" (point 2) represents the extreme limit where only the total energy import is minimized. The difference in the importation costs for points 1 and 2 show how far the substitution of alternative sources for imported energy can be pushed, thereby illustrating the fragility of the energy system. In the "Decay Case" (point 3) the total cost of the supply subsystem minus import is minimized. This is an unrealistic situation because it represents a world where there is plenty of cheap oil, resulting in the use of as much oil as possible.

Fig. 4.1. Total actualised system costs against total actualised import costs. The units are 10^{11} ecu 1978.

1. Reference case
2. Mining case
3. Decay case
4. Antonomy case
5. Dependency case.



Point 4, the "Autonomy Case" represents a situation in which the import bill is reduced and substitution is enhanced as far as the economy allows.

The "Dependency Case", point 5, represents a policy with the sam total costs as point 4, but with imports preferred to in- vestments.

The total actualised system costs, import costs, and supply cost for the five case studies are shown in Table 4.3. These result show that it is possible to reduce the value of the total energ import by 11% with respect to the reference case (point 1) by a increase in the total cost of 19%. For points 4 and 5 th objective function was fixed at a value 8% above the referenc case (107.7) which corresponds to an increase in the total cost of 8%.

Table 4.3. The actualized costs in the five case studies.
(The units are 10^9 ecu 1978)

Case	System costs	Import costs	Supply costs
1. Reference	107.7	34.99	16.75
2. Mining	128.7	31.5	22.38
3. Decay	157.7	70.11	11.20
4. Autonomy	116.4	32.03	13.58
5. Dependence	116.4	45.28	13.88

After this first case study with EFOM, the work has reached stage where it is possible to assess the suitability of the model for planning the future energy system in Denmark. In this respect a number of problems can be identified, for example, the difficulty of interpreting the results because of the model's complex structure, inappropriate sector divisions for Denmark and a high degree of dependence on economic and technical data which are often difficult to obtain and require frequent updating. In addition to these problems, there is some doubt as to the value of using the linear programming method, and optimisation techniques in general, for the study of future national energy supply systems. In view of these considerations, our attitude to the EFOM model as a planning tool is somewhat sceptical. It is felt that a simulation approach would be more appropriate.

5. OTHER EXTERNAL PROJECTS

5.1. Survey of Danish energy statistics

In the summer of 1981 a contract group with representatives from the Ministry of Energy, the Energy Agency, and the Danish Statis- tical office was formed with the aim of identifying shortcomings and duplications in the Danish Energy Statistics and to encourage homogeneity with respect to definitions and groupings. This group initiated a contract with ESG to undertake a survey of Danish energy statistics. The first version of the survey is designed for use in the central administration and contains a standardised description for each set of statistics with the following headings:

Name
Frequency
Production time
Preparing institution
Input data used
Form of publication
Length of time series
Energy types and their units
Energy flows and stocks mentioned
Confidence
Observed problems

An example of each set of statistics along with the relevant questionnaires is attached to each description.

The results of the survey are presented in hierarchical form beginning with energy types, thus facilitating rapid access to the required documentation.

The second version of the survey will be aimed at a broader clientele and will contain descriptions of items of more general interest.

5.2. Natural gas - security of supply

During 1981, ESG participated in an analysis of security of supply in the Natural Gas Network which several departments of Risø National Laboratory have carried out for the Danish Energy Agency, the Danish Oil and Natural Gas Company (D.O.N.G.), and the Municipal Natural Gas Companies (KOMGAS). The aim of this analysis was (1) to update an earlier analysis of the national transmission network, and (2) to make a comparison of the security of supply in the transmission network and regional and local distribution networks.

The study has shown that the security of supply in the regional and local distribution networks is much better than in the transmission network, that ring-structures in the distribution networks will secure the demand for most consumers in case of leaks except under extreme weather conditions, and that the greatest risk for a prolonged lack of supply would be a leak in crossing either of the two Belts. For this reason a duplication of the Great Belt crossing, which entails the greatest risk, was recommended.

5.3. Energy technology characterisation

A number of energy technologies were examined and characterised as part of the IEA Energy Technology Systems Analysis project. These technologies included heat pumps, solar energy collectors and windmills. The purpose of the work was to establish a set of data which could be used as input for future energy system studies to be carried out by IEA.

The work was not without its difficulties, a predominant one being the definition of precise and easely understandable descriptors for the various technologies. A consequence of this was the realisation of the necessity of imposing suitable discipline on potential users of the material so that the data is used as intended. Without such discipline it is felt that the work would be essentially wasted.

This work was carried out in collaboration with the Physics Department, Risø.

6. NEW PROJECTS

A number of new projects were started by the end of 1981 or were just about to start in the beginning of 1982. In order to give an impression of the scope of work of ESG at the end of the reported period, a short introduction to the new projects is given below.

6.1. Small- and medium-size coal installations

The increased use of coal has an important role in Danish Energy planning and the energy research programs. Some major projects in the research program on coal are the study of different coal-burning technologies, coal-classification, and coal-transportation.

The aim of this project will be to illustrate some technical and economic consequences of the introduction of small and medium-size coal installations into the Danish energy system, e.g. the change from oil to coal in district-heating plants. The project is carried out as a collaborative effort among the Danish Boiler-Owners Association, The Danish District-Heating Association, and Risø, the latter represented by ESG.

The study will consist of an analysis of single installations and an analysis of the local and national energy system. New coal-fired district-heating plants of different sizes and technologies will be compared with plants in which oil-firing is continued or gas-firing is introduced according to the Natural Gas Plan. The size of these plants will vary between 1 MW and about 40 MW. The system analysis is expected to emphasize coal qualities together with transport and infrastructure, combination of installations in the local energy system, and the role of coal installations in the national energy system.

6.2. Nordic energy system study

The Nordic Council of Ministers has initiated a preproject con cerning a Nordic energy system study. The overall aim of th study is to identify potential areas for extended Nordic col laboration in the energy sector. The project will involve a comparative analysis of the energy plans and energy research an development plans of the Nordic countries. The study is carrie out as a joint venture of the four Nordic Energy Researc Institutes. The preproject is to be completed in the autumn o 1982.

6.3. Nordic heat supply study

Paralleling the above-mentioned Nordic energy system study, th Nordic Council of Ministers has initiated a Nordic heat suppl study. The study will focus on the potential gains obtainabl from further collaboration among the Nordic countries in the hea supply area. The main emphasis will be on the technical aspects The study is carried out as a joint venture with Studsvik Sweden, The Technical Research Centre of Finland and Th Electricity Supply Research Institute, Norway. The preproject i to be completed in the autumn of 1982.

6.4. Wind power in the Faroe Islands and Iceland

Under the auspices of the Nordic Co-operative Organization fo Applied Research a preproject has been initiated concerning th introduction of windmills into an electricity supply syste presently based on diesel generators and hydropower. The stud will cover the major Faroese electricity supply system and som smaller isolated islands. The preproject is carried out in col laboration with the Energy Council of the Faroe Islands and th State Electricity Supply Company of Iceland. The preproject is t be completed by the summer of 1982.

6.5. Assessment of the technical and economic prospects for wind energy in the EEC countries

In March 1981, the Advisory Committee for Program Management for the European Commission's solar energy programme initiated a study of wind power. The Energy Systems Group was awarded a contract to carry out part of the study, namely the assessment of technical and economic prospects for wind power in Denmark. Work on the study began in November 1981 and by the end of the year an outline of the content of the study had been formulated. The expected completion date of the study is June 1983.

7. PUBLICATIONS AND LECTURES

7.1. Publications

The major part of the group's work during 1981 consisted of special jobs for the Energy Ministry and contract work for the European Commission, for which a number of reports and memoranda were prepared. Because of the nature of the work, however, these documents are not, in general, available to the public. The reports listed below have recently been made publicly available by the European Commission.

J. Fenhann, P.E. Morthorst. "Energy models for Denmark: EXPLOR-EDM-EFOM, Final report". EUR 7274 EN.

J. Fenhann. "A case study with the energy supply model EFOM-12C. Final report". EUR 7378 EN. 53 p.

P.E. Morthorst. "Energy models for Denmark: EXPLOR-EDM case studies: Base and high case. Final report". EUR 7390 EN. 39 p.

7.2. Lectures

J. Fenhann	"The Danish energy situation", Energy Law institute, Concord, New Hampshire, USA, 19 August.
H. Larsen	"Danish energy planning after 1973 and the implementation of the decisions". Watt Committee 10th consultative Council Meeting on "The European Energy Scene", London, 21 May.
H. Larsen	"Review of recent developments in wind energy systems". Seminar on "Wind Power Technology", Shelbourne Hotel, Dublin, 2 April.
P. Laut	"Heat pumps", at "Byggeri for Milliarder" Exhibition, Bella Centre, Copenhagen, Februar.
G.A. Mackenzie	"The long-term energy demand model MEDEE", Energy Systems Analysis Seminar, Risø 26 November.

8. STAFF

Leader:
Hans Larsen M.Sc. (DtH*), Ph.D. (DtH).

Physicist with postgraduate research in reactor technology, with the Reactor Technology Department at Risø from 1970 until 1980.

Visiting scientist at UKAEE Winfrith 1073-76 working on the OECD Dragon project. Joined ESG as leader in July 1980. Member of the following national and international committees:

* Technical University of Denmark.

- A joint Nordic group for non-nuclear energy research.
- Advisory Committee on Energy, Danish Association of Electrical, Chemical, Mechanical, and Civil Engineers.
- European Commission ACPM on Energy Systems Analysis and Strategy Studies.
- Danish National Committee of World Energy Conference.

Took part in the EP-81 working groups concerned with domestic energy production and technical aspects of the supply system. Member of the working group dealing with long term energy planning.

Deputy Leader: (until June 1981).

Jens Houmann M.Sc. (DtH), Ph.D. (DtH).

Physicist with postgraduate research in solid state physics, with the Physics Department, Risø, from 1968 until 1977. Founding member of ESG and acting leader 1979-80. On leave from ESG from June 1981, now working in the Ministry of Energy.

Deputy leader: (since June 1981).

Poul Erik Morthorst M.Econ, (Århus).

Economist specialised in econometric forecasting. Research assistant at Institute of Economics, Århus University from 1976 to 1977. Joined ESG in June 1978. Main activities within ESG include the implementation of the EC medium-term model and general government energy planning, especially forecasting of electricity demand. Took part in the EP-81 working groups for electricity demand. Involved in project on Scandinavian energy system analyses. Working with economics of renewables and member of advisory group set up by the Energy Agency to study renewable energy in rural communities.

Permanent staff:

Frits Møller Andersen M.Econ. (Århus).

Economist specialised in computer modelling and econometrics. Worked as teaching assistant in the Institute of Statistics, Århus University and as economic planner in local government before joining ESG in May 1980. Main activities within ESG con sist of the development, implementation, and use of econometri models for energy demand forecasting, in particular the develop ment of the macrosectoral model. Participated in the EP-81 work ing group on process energy.

Peter Skjerk Christensen M.Sc. (DtH).

Physicist with previous experience in reactor physics in th Reactor Technology Department, Risø, before joining ESG as founding member. Activities within ESG include modelling o electricity and heat production and transmission systems, model ling of total energy systems, and maintaining an up-to-dat knowledge of the construction and operation of power reactors an of the nuclear fuel cycle. Participated in the EP-81 workin group on technical aspects of the energy supply system.

Jørgen Fenhann M.Sc. (Copenhagen).

Physicist with mathematics and chemistry as subsidiary subjects After 1 year of teacher training taught at high school and DtH Since July 1977 worked on the EC energy model programme, firs with the Niels Bohr Institute, University of Copenhagen, and sin ce November 1978 with ESG. Activities within ESG include th survey of energy studies involving windpower, and the running o the energy-flow optimisation model.

Poul Erik Grohnheit M.Econ. (Copenhagen).

Economist, before joining ESG worked with the Danish Building Research Institute (1969-71), as a town planning consultant (1971-72 and 1979-80) and on economic planning in local govern ment (1973-79). Joined ESG in May 1980. Main interests within ES include energy economics, town planning, and local government with particular emphasis on space heating. Member of the EP-8 working groups concerned with space heating and the economi analyses of the power generation system.

Niels Kilde M.Sc. (DtH).

Graduated in 1962 as chemical engineer with special emphasis o metallurgy. Master's thesis on industrial galvanising. From 196

to 1981 employed at the Danish Steelworks Ltd., Frederiksværk as deputy department manager in the laboratory (1962-67), personal assistant to the technical director (1967-72), department manager for production and head of planning and implementation of new continuous casting plant (1972-77). During the final period, as development and energy manager (1977-81),responsible for the reconstruction of electric arc furnaces and the utilisation of cooling water for the heating of the entire works and the district heating of the neighbouring town of Frederiksværk.

Joined ESG in September 1981. Activities include long-term energy planning, coal technology, and Scandinavian heat planning.

Gordon A. Mackenzie B.Sc. (Edinburgh), Ph.D. (Edinburgh).

Physicist with postgraduate work in solid state physics. First came to Denmark in 1974 to participate in physics experiments at Risø. Postdoctoral work in Physics Department, Risø 1976-78. Lecturer in physics at Edinburgh University 1978-79. After a further period at Physics Department, Risø, joined ESG in February 1980. Main interests within ESG are the long-term demand model MEDEE, transport energy, and the use of wind power in small systems. Took part in the EP-81 working group on transport energy.

Jørgen Marstrand M.Sc. (DtH), D.Techn. (DtH).

Mechanical engineer with experience in the shipbuilding industry and the Danish Factory Inspectorate before joining Risø in 1957. Doctoral thesis "Methods of Hydrodynamic Computation of Ship Propellers" published 1952. Former head of Engineering Department at Risø and chairman of the Safety Committee for the DR2 reactor. Played a leading role in the design and construction of various installations at Risø, including the Hot Cell. Contributions within the field of reactor technology include the invention of a new type of fuel assembly for boiling-water reactors employing a hexagonal arrangement of fuel rods and twisted deflectors. Active participant in the public debate on future energy sources and the role of nuclear power. Worked with the Reactor Technology Department, Risø, before being attached to ESG in 1980. Recent activities have included the collection and examination of technical and economic data for energy conversion systems for use in EP-81.

Erland Hejn Nielsen M.Math.-Econ. (Århus).

Mathematical economist specialised in economic modelling an econometrics. During period of study worked as programming as sistant at the Institute of Economics, University of Århus Joined ESG in June 1981. Main activities within the Group are th development and implementation of the EC Macrosectoral Model.

Postgraduate Students:

Henrik Andersen M.Sc. (DtH), B.Com. (HHK*).

Mechanical engineer with postgraduate qualification in economics From Febuary 1978 until September 1979 worked at DtH on estimat of design parameters for cooling towers at the Mechanical Engi neering Department and the Danish Solar Heating Programme at th Thermal Insulation Department. Awarded a scholarship by Danis Council for Scientific and Industrial Research to work on th study programme on energy and economics, project on pricing po licies and tariff structures in space heating begun October 197

Helge V. Larsen M.Sc. (DtH).

Graduated in electronic engineering in 1974 and subsequentl worked as a university demonstrator at DtH and as an electroni engineer in industry. Joined Risø National Laboratory in 197 engaged in computer modelling of radiation heat transfer in BW fuel elements with the Reactor Technology Department. Late worked on Nordic project on modelling of district heating sy stems, based at Studsvik Energiteknik, Sweden. Currentl developing a model for the simulation of power station operatio

Research Fellow:

Lars Henrik Nielsen M.Sc. (Copenhagen).

Physicist with mathematics as a minor subject. Master's thesi described a model for a solar heating system with a central hea storage combined with a district heating system. Worked as hig school teacher and teaching assistant at the University of Co

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* Copenhagen Scool of Economics and Business Administration.

penhagen during period of study. Joined ESG in August 1981 as research fellow. Currently working on a model to describe the economic characteristics of renewable energy technologies.

Consultants:

Peter Laut, Professor, Engineering Academy of Denmark.

Svend Vørts, Professor (retired) Electrical Power Engineering, Technical University of Denmark.

Undergraduate assistant:

Jesper Schmaltz-Jørgensen.

Secretaries:

Jette Larsen

Susanne Valentin Nielsen

Short-term guest researcher

Cynthia Johnson

Science Policy Research Unit,
University of Sussex,U.K.